Faecal NIRS — what does it offer today's grazier?

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Abstract

Faecal NIRS (the analysis of faeces by near infrared reflectance spectroscopy) is being developed for application in the cattle grazing industry of northern Australia. Calibration equations have been developed for predicting dietary crude protein, digestibility, proportion of non-grass in the diet and faecal nitrogen concentration. Other equations are being developed to predict dietary neutral detergent fibre, acid detergent fibre, digestible organic matter intake and rate of gain in growing cattle. The technology lends itself to commercial adoption because of the simplicity of sampling and analytical procedures, the rapid turn-around between sampling and availability of results, the range of attributes that can be predicted from a single analysis and low cost compared with conventional laboratory analysis. Faecal NIRS is described primarily as a decision support tool via the ability to capture relevant quantitative information on dietary nutritional status and growth performance of grazing cattle as well as via an improved knowledge and understanding of the nutritional aspects and complexities of rangeland systems. Perceived benefits and current limitations are described.

Introduction

Faecal NIRS technology was pioneered by scientists at Texas A&M University in USA where calibration equations were developed for predicting the crude protein and digestible organic matter concentrations in the diet selected by free ranging cattle (Lyons and Stuth 1992). The development of faecal NIRS technology for use in Australia began in 1994 and to date it has been confined to research based at the CSIRO Davies Laboratory in Townsville. The focus has been on developing a technology for application across the tropical and subtropical rangelands of northern Australia. This paper describes various aspects and outcomes of this program, especially as they relate to potential commercial applications.

NIRS is a secondary method of analysis whereby the attribute being determined can be estimated from the NIR reflectance characteristics (NIR spectrum) of the substance being analysed. The estimates are based on calibration equations developed by relating attribute value (determined by a primary analytical technique) to NIR spectra of a large and diverse set of samples known as the calibration set. In most applications, the NIR spectra and attribute values relate to the same samples (*e.g.* protein content of forage or grain). Faecal NIRS differs to the extent that the attributes being estimated include not only faecal properties *per se* but those of the diet and animal performance attributes.

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Range of attributes

The initial work aimed at developing calibration equations for predicting crude protein and digestibility. Subsequently the scope was increased to include:

Dietary nitrogen (N) or crude protein (CP) concentration.

Dry matter digestibility (DMD) of the diet.

Neutral detergent fibre (NDF) in the diet. The dry matter in forage can be divided into cell contents (which are soluble in neutral detergent and readily digested) and cell wall constituents (which are insoluble in neutral detergent and less readily digested or indigestible). The NDF fraction represents the cell wall constituents. Digestibility and voluntary intake are both negatively correlated with NDF but the relationships for grasses and legumes differ.

Acid detergent fibre (ADF) in the diet. ADF represents that fraction of the cell wall constituents that is not soluble in acid detergent. Digestibility is more closely correlated with ADF than NDF and the relationship is similar for grasses and legumes.

Dietary grass and non-grass proportions. The non-grass components include sown legumes, forbs and browse.

Faecal N concentration. Faecal N is predominantly of microbial and endogenous origin and has been used as an indicator of the adequacy of rumen degradable nitrogen (Winks *et al.* 1979).

Growth rate. Growth rate is affected by animal as well as dietary factors so that faecal NIRS predictions of growth rate will be developed for a standard animal (*e.g.* for a 300 kg steer of medium frame size in store condition). Predicted growth rate would then be adjusted for the sex, age, weight and condition of the animal in question.

Digestible organic matter intake (DOMI). DOMI combines the measurements of digestibility and forage intake and is therefore a good index of the productive potential of the diet.

Calibration sample sets with associated calibration equations have been developed for predicting CP, DMD and non-grass proportions in the diet as well as faecal N concentration (Coates 1999). The calibration sets for predicting dietary non-grass proportions and faecal N concentration are comprised of a wide diversity of samples from across northern Australia. In contrast, the calibration sets for predicting dietary CP and DMD are comprised of samples from a limited number of sites in north-east Queensland. However, the samples represent a diversity of pasture species and mixtures, stages of growth, soil types, seasons and years. Although all current calibration equations require significant expansion by including increased number and diversity of samples in the calibration sets to improve the accuracy of predictions, the present equations are already being used in grazing trials and commercially.

Practical aspects of faecal NIRS

Before considering the applications of faecal NIRS it is appropriate to understand the practicalities of the technology in terms of sampling, analysis, timeliness and costs.

Sampling faeces for analysis is simple and easy. The requirement is for a composite sample of fresh, uncontaminated faeces that is representative of the herd being tested. There is only limited knowledge of the effect of faecal pat age on faecal NIRS predictions. For pelleted faeces (*e.g.* sheep and goats), exposure to the environment has little effect on dietary CP and digestibility predictions for up to 7 days (Leite and Stuth 1994). Predictions on cattle faeces did not change during 48 hours exposure when tested at Lansdown Pasture Research Station (Lansdown) near Townsville (D.B. Coates, unpublished data). Since there is usually no difficulty in collecting fresh faecal samples either per rectum from yarded cattle or from fresh faecal pats in the paddock, fresh material is recommended.

Samples should be sealed in a suitable labelled container such as a zip-lock plastic bag and frozen as soon as convenient after collection. Some insulation (*e.g.* wrapping in newspaper) is recommended during transport to the analytical laboratory. The effect of transit time on faecal NIRS predictions has been examined (D.B. Coates, unpublished data). Long transit times can result in changes in faecal NIRS predictions. These changes are promoted by high ambient temperature, high faecal moisture content and high forage quality. Under most conditions, however, faecal NIRS predictions remain stable for about 5 days after samples are removed from the freezer.

Sample processing prior to NIRS analysis is minimal. It involves drying in a forced-draft oven (60–65°C) and grinding in a suitable laboratory mill. NIRS analysis of the dried, milled faeces averages only a few minutes per sample. Thus, faecal NIRS predictions can be available within 30 hours of receiving a fresh sample and within a week of sample collection. All attributes for which calibration equations have been developed may be predicted from a single NIRS analysis.

The practicalities as outlined above ensure that the critical requirements of simplicity, timeliness and low cost can be met. The other critical requirement, *viz.* reliability, will be considered later.

Applications of faecal NIRS

Faecal NIRS can be beneficially employed in a variety of research and commercial applications but the emphasis here will be on applications of potential benefit to producers.

A tool for cost-effective supplementation

The most obvious application is as a decision support tool for cost-effective supplementation. The diet of grazing cattle is subject to continual change in chemical composition, nutrient balance and productive capacity. Cost effectiveness in supplementation necessarily depends on a knowledge of current diet quality together with a knowledge of nutrient requirements so that the supplementary nutrients needed to meet production targets can be determined at any point in time (the when, what and how much to feed). Previously it has not been possible to make reliable estimates of current diet quality in extensively grazed cattle due to:

- heterogeneity of rangeland pastures;
- selective grazing which often results in diet quality being poorly correlated with the quality of pasture on offer; and
- large climatic variability which results in the seasonal pattern of diet quality being highly variable between years, this latter factor ensuring that current diet quality cannot be predicted according to the calendar.

With faecal NIRS technology it is now possible to obtain relevant and timely information on the protein and energy status of the diet so that producers or their advisers can make decisions on when, what and how much supplement is needed.

Figure 1 gives an example of the sort of differences that can occur between years in the seasonal pattern of diet quality. Faecal NIRS predictions indicated that dietary CP concentrations remained above 8% throughout 1998 except for the 3-month period, June–August. Estimates of dietary CP under 6% occurred only in August. The former concentration (8%) meets the recommended protein requirements for growth rates of about 750 g/d while the latter concentration is suggested as both the minimum concentration needed to meet the requirements of rumen bacteria and the maintenance requirements for young cattle (Minson 1990). In 1999, however, there was a rapid decline in dietary CP during April–May leading to sub-maintenance dietary CP concentrations for the 5-month period, June–October, inclusive. The protein deficiency experienced in 1999 was associated with low proportions of stylo (*Stylosanthes hamata* cv. Verano and *S. scabra* cv. Seca) in the pasture (data not shown) and the diet (Figure 1) during the dry season. Supplementation with either protein or non-protein nitrogen would probably have been effective during the dry season of 1999 but unnecessary in 1998. Faecal NIRS predictions for cattle grazing pastures with no sown legume in the Charters Towers region in 1999 indicated that dietary protein deficiency began as early as mid-April and that protein deficiency was widespread by mid-May (Table 1).

Table 1. Faecal NIRS predictions of dietary crude protein (CP) concentrations in the Charters Towers district during 1999.

Property	Pasture type	Dietary CP (%)			
		March	April	May	June
Eumara	Indian couch	7.6	6.8	5.4	4.1
Forest Home	Indian couch	6.8	5.6	3.9	2.5
Cardigan	Indian couch	8.1	7.1	5.6	3.6
Larkspur	Native grasses	7.6	5.1	4.5	3.4
Doongara	Native grasses	7.3	5.6	5.2	4.8
Merricourt	Buffel	7.6	6.6	5.4	4.1
Wambiana	Native grasses			5.1	3.0

Depending on the aims of the supplementation program, the amount and formulation of the supplement may need to be modified in line with progressive changes in the basal diet. Fortunately, the evidence to date from both pen and field analyses suggests that the feeding of supplement has minimal effect on faecal NIRS predictions of the forage consumed. This means that the quality of the basal diet can be monitored even when supplement is being fed and appropriate changes to the supplementation regime can be implemented.

A tool to enhance timely decisions

Timeliness of decision making is one of the strengths of good managers and is of critical importance to effective supplementation strategies. However, other important decisions often need to be made as the result of the changing nutritional status of grazing cattle, usually as a consequence of declining nutritional status. Here, also, faecal NIRS has great potential as the tool to facilitate timely decisions. Some examples follow.

Cattle movements. There are many instances when cattle have to be moved from their "home" paddock (paddock to paddock within a property, paddock to paddock between properties or paddock to feedlot) and where the optimum timing of the transfer is dependent on, among

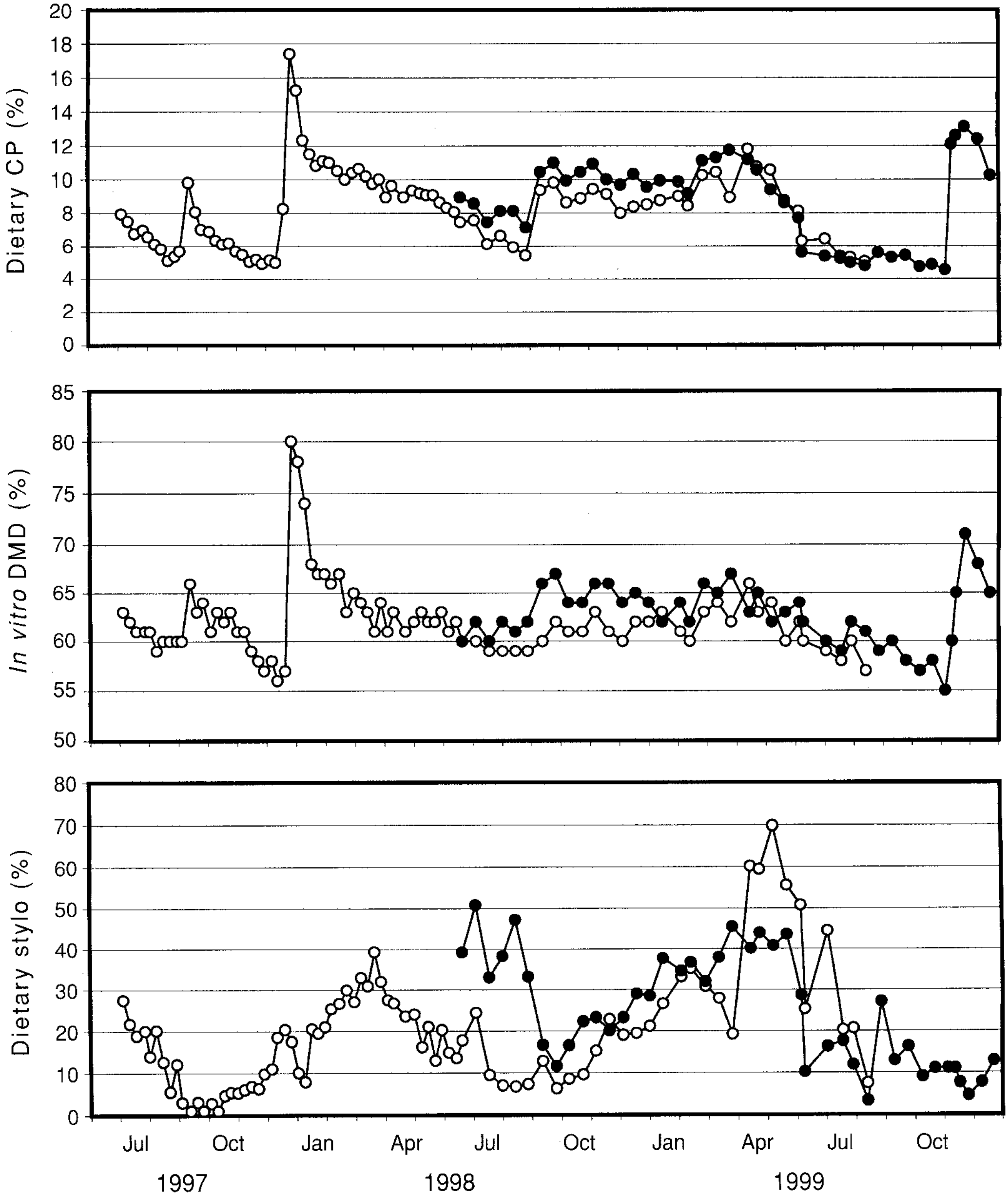

Figure 1. Faecal NIRS predictions of dietary crude protein (CP), *in vitro* dry matter digestibility and dietary stylo proportions in cattle grazing Urochloa/stylo pasture. ○ = No. 7 heifers; ● = No. 8 steers.

other things, the current nutritional status and performance of the cattle. Faecal NIRS has the potential to provide critical decision support on current diet quality and growth rate that has hitherto been unavailable to managers. If diet quality and growth rates are satisfactory in the "home" paddock, it may be inopportune to move the cattle whereas deteriorating diet quality and performance may require urgent action to avoid production losses. Reliable predictions of growth rate from faecal NIRS would have significant advantages over weighing cattle because:

- faecal NIRS predictions provide a growth rate estimate at the time of sampling whereas

weighing can provide only average growth rates between weighings;
- faecal NIRS predictions of growth rate provide estimates of tissue-related growth rate that are not confounded by gut fill whereas weighing cattle often confounds growth rate with variable gut fill; and
- collecting faecal samples from the paddock is simple and inexpensive compared with mustering and weighing. The economic benefits to a large-scale enterprise with feeder cattle destined for finishing in the feedlot and where decisions have to be made on a continuing basis regarding the flow of cattle from pasture to feedlot would be substantial.

Weaning. Monitoring diet quality by means of strategic faecal sampling and analysis can provide the quantitative information on dietary nutritive status needed to make informed decisions about timely weaning schedules. Early weaning benefits the cow while later weaning benefits the calf (and the manager if early weaned calves have to be fed) so there is usually a conflict of interest in choosing the most appropriate weaning date, especially in the more northern regions with a long but variable dry season. In general terms, weaning needs to be early in 'poor' seasons to avoid jeopardising future reproductive performance and/or cow survival, whereas weaning can be delayed in 'good' seasons without risk to the cow but with benefits to the weaners and to management. In practice, however, it is often difficult to differentiate between 'good' and 'not-so-good' seasons except with hindsight. Seasons which at first appear to be 'good' may turn 'poor' in respect of dietary nutritional status sooner than expected but without obvious visual cues.

Agistment. In some instances, faecal NIRS may help producers make decisions on choosing between agistment alternatives or in negotiating appropriate agistment fees based on estimates of current diet quality together with evidence of feed quality from previous faecal profiling records. Additionally, faecal NIRS could help owners to monitor the nutritional status and expected performance of agisted cattle from a distance and so enhance their capability of making timely decisions in absentia.

Forward marketing. A number of issues are becoming increasingly relevant to efficient and profitable livestock production. These include age of turnoff and throughput of growing cattle, meeting market specifications, consistency in product quality and the targeting of specific markets. Being able to control these aspects of production presents significant challenges to managers operating under conditions of extreme climatic variability. Even under the rather favourable conditions at Lansdown Research Station near Townsville, average annual liveweight gains on sown grass-legume pastures vary enormously in the range of <80–>200 kg (Jones *et al.* 1990; D.B. Coates, unpublished data). Advances in supplementation technology have provided new opportunities for managers to meet market specifications in spite of nutritional variability between years but there is a real need to be proactive rather than reactive in implementing appropriate strategies. Proactive decisions need to be based on appropriate information relating to current status and future projections. Faecal NIRS has the potential to provide the necessary information on current animal status (diet quality and growth rate) while the same information can assist in making future projections. The ability to project future diet quality and animal performance from current status should improve with accumulated experience based on faecal profiling. Regular monitoring of cattle for estimating diet quality and growth rate should allow producers to determine whether cattle are on track to meet the target market specifications and turnoff dates. If they are not, the producer can be proactive in assessing the alternatives that are available, such as production feeding to ensure the target is achieved, preparing for an alternative market, or doing nothing. Decisions will also be influenced by the prevailing economic circumstances, the future consequences of failing to meet the planned market and turnoff schedule, and personal attitudes to risk taking.

Faecal profiling and resource monitoring

Needs, limitations and opportunities. Livestock production is making increasing demands on the knowledge, skills and expertise of producers and the way they manage their resources. These demands result from:
- increasing pressure on production efficiency and enterprise viability;
- consumer preferences for improved and consistent product quality;
- community pressures on responsible and sustainable land management; and
- animal welfare issues.

For example, with the current attitudes towards the environment and sustainable production, resource monitoring is receiving increased attention. In terms of the forage resource, however, effort has been directed primarily towards the species composition of pastures, yield and ground cover. While this effort is to be applauded, the implications for the quality of the diet of grazing livestock is not directly addressed. It seems logical, therefore, that this type of monitoring be complemented with the monitoring of diet quality in free-ranging livestock.

The quality of the diet is probably the most important determinant of livestock productivity and meat quality but the one which is the least understood in rangeland production systems. There have been countless "experiments" involving the chemical analysis of pasture samples with determinations of N or CP, *in vitro* digestibility, crude fibre, NDF, ADF and ADL (acid detergent lignin), and an array of minerals. The samples analysed have ranged from total pasture on offer, to individual plant species, to plant parts within species, to mixed forage samples plucked so as to simulate the diet selected by the grazing animal. Samples are often collected according to a predetermined schedule to track the seasonal fluctuations in the attributes measured. These plant analyses have provided a wealth of information on the nutritive value and limitations of pasture on offer to grazing herbivores. Unfortunately, no amount of chemical analysis of hand-harvested plant material can provide reliable estimates of the chemical composition or nutritive value of the diet of free-grazing livestock in all but the most intensive situations. Likewise, using oesophageal fistulated cattle for collecting representative diet samples is unreliable (Coates *et al.* 1987; Jones and Lascano 1992; Clements *et al.* 1996).

Animal faeces have long been targeted by scientists to provide information on the botanical and chemical composition of the diet, usually with limited success. The determination of dietary C_3:C_4 composition from faecal carbon ratios (Jones 1981) and estimates of botanical composition, digestibility and intake using faecal alkane analysis (Dove and Mayes 1991) are notable exceptions, whereas faecal NIRS technology represents a significant scientific breakthrough in unlocking the storehouse of information within faecal material. It provides a powerful tool to rectify the limitations resulting from our previous inability to readily and reliably determine diet quality in free-grazing livestock.

Diet quality, a major driving force behind productivity, can be continuously monitored using faecal NIRS technology through the simple process of faecal sampling, drying, milling and analysis at any desired frequency. The results assembled over a given period, and most conveniently presented in line graph form (Figure 1), provide a nutritional profile of diet quality for the target animals. The practicalities of faecal NIRS mean that faecal profiling (developing profiles of diet quality or performance attributes by means of faecal NIRS) is accessible and affordable to researchers, producers and consultants alike. It provides a new and powerful tool for greatly improving the knowledge and understanding of the nutritional potential and limitations of rangeland resources, knowledge and understanding that can facilitate better and more timely decision making, better resource management, increased production efficiency and improved long-term economic viability.

Dietary crude protein and energy status. Faecal profiling for CP concentration and energy status of the diet over time will allow forage resources to be assessed and rated according to their potential for animal performance (reproduction, milk production, growth rate) by comparing the estimated dietary attributes with known nutrient requirements for different performance levels. The severity and duration of nutrient limitations can be readily identified and correlated with seasonal and weather conditions (rainfall and soil moisture, temperature, frosting), soil type, vegetation (grasses, legumes, forbs, browse) and management interventions (grazing systems, fire, pasture renovation). Pastures can be characterised in terms of maximum and minimum nutritive levels, rates of change in nutritive value and the contribution of different species or types of forage to diet quality. Some of these aspects are illustrated in Figure 1 for a Urochloa (*Urochloa mosambicensis*) and stylo pasture at Lansdown.

In this illustration, predicted digestibility is used as an index of dietary energy status because a reliable equation has not yet been developed to predict digestible organic matter intake (the product of intake and digestible organic matter) which is the preferred measure of dietary energy status. Peak CP and digestibility predictions (17.4% CP and 80% digestibility) occurred in December 1997 soon after the start of the wet season. These can be regarded as the maximum likely values for that particular pasture/soil type/grazing system but the peak values were quite ephemeral and within 2 weeks there was a 30% reduction in dietary CP concentration. Excellent rainfall ensured that the pasture remained green for the first half of 1998 but there was a decline in diet quality associated with progressive physiological maturity of both grass and legume components together with a declining proportion of stylo in the diet. This contrasted with the following wet season where, up to the end of April, declining CP levels in grass were balanced by increasing proportions of dietary stylo. This was followed by a rapid fall off in dietary CP due to both moisture stress and a lack of stylo. By mid-June of 1999, dietary CP levels had bottomed out and remained fairly stable at around 5% until the end of the dry season in November. There was a trend for digestibility levels to decline throughout the dry season. The balance between dietary CP and digestibility is also of importance. The moderate digestibility predictions associated with low CP predictions for the 1999 dry season suggest that good responses to feeding with urea-based supplement could have been achieved.

Grass and non-grass dietary components. Grass is the major forage resource for grazing cattle in most rangeland systems but forbs (including legumes) and browse are known to contribute to cattle diets to a greater or lesser degree depending on a whole host of interacting factors. However, a proper assessment of the magnitude and importance of non-grass plant material to the diets of cattle in different situations has not been possible because of the difficulties and/or cost involved in acquiring sufficient qualitative and quantitative information. Some of these difficulties have been overcome by the development of a faecal NIRS calibration equation for predicting the proportion of non-grass consumed by grazing cattle. The current calibration equation is actually based on faecal carbon ratios ($\delta^{13}C$) from which dietary C_3:C_4 proportions can be calculated (Jones 1981). As such, the current predictions are valid only for tropical and subtropical systems where the grasses are C_4 species and where the non-grass components are C_3 species.

Diet quality is often significantly enhanced by forbs and browse with important consequences for animal performance. Non-leguminous as well as leguminous forbs often have higher CP concentrations and digestibilities than grass and some are important sources of minerals. Browse generally makes its main contribution in the dry season when grass quality is low as well as in drought years when grass is scarce. Apart from the contribution of browse to energy intake, it provides additional dietary N when grass is deficient in protein.

Faecal profiling for dietary non-grass proportions has been quite illuminating with regard to the magnitude of the non-grass contribution to rangeland cattle diets. An example is presented in Figure 2 showing contrasting seasonal patterns from different soil/vegetation classes. At Larkspur

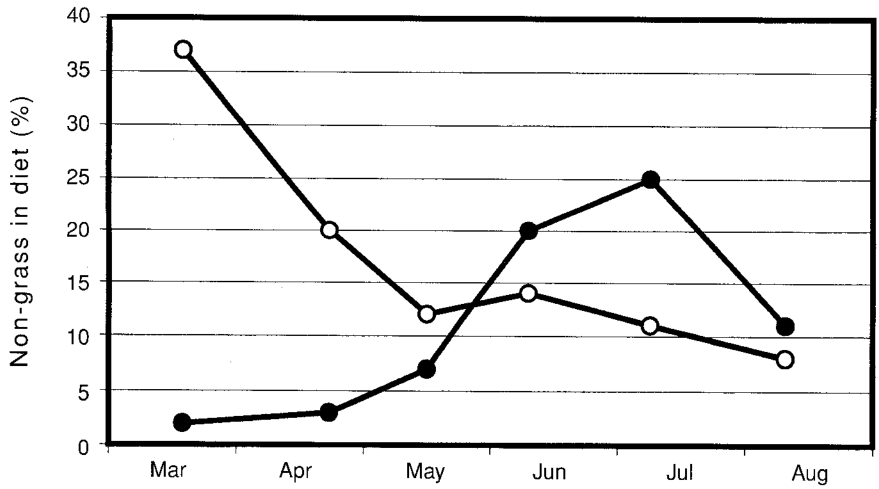

Figure 2. Dietary C_3 proportions (non-grass) in the diets of cattle at Larkspur (●) and Bluff Downs (○) from March–August 1999.

just north of Charters Towers, there is an abundance of edible trees and shrubs. Dietary non-grass was negligible in March 1999 (late wet season) indicating an absence of edible or palatable forbs but there was a progressive increase in non-grass proportions well into the dry season as browsing increased. A contrasting pattern was observed in a paddock at Bluff Downs where more than one-third of the diet was non-grass in March (probably native legume and other forbs). There was a progressive decline in non-grass from March to May, when levels were just over 10%. This was probably associated with decreasing palatability and/or availability of forbs and the absence of browse shrubs and trees. At Lilyvale near Richmond in north Queensland, faecal NIRS predictions for dietary non-grass proportions averaged 33% (maximum level of 50%) for the period May–November 1999 in a paddock with native speargrass pasture and a woodland with species known to provide browse. These examples were recorded after a better than average wet season so that grass was plentiful throughout the dry season. Figure 1 illustrates faecal profiling of non-grass (predominantly stylo) in the diet of cattle grazing stylo-based pasture at Lansdown. C_3 species other than sown stylos were virtually absent. Faecal profiling of dietary non-grass proportions using NIRS provides a simple, inexpensive way of gaining a greater understanding of the different vegetative components contributing to the diet selected by free-ranging cattle and their effect, not only on productivity, but also on the nutrition of cattle during regular seasonal troughs or periodic drought. With further research and development, it may be possible to expand the scope of faecal NIRS for predicting dietary botanical components.

Building up regional knowledge. The benefits of faecal profiling would be maximised by co-ordinating efforts on a regional basis. Over a number of years, a wealth of information could be accumulated in a data base for each region for providing information on nutritional attributes and limitations, diet composition, and growth performance in relation to soil type, vegetation, season, seasonal variability, effective supplementation strategies and so forth. Producer networking which would facilitate a coordinated approach to resource monitoring is already established in many localities. Technology transfer and decision support based on a system of regional experts is one way to promote the effective use of the faecal NIRS technology. The interpretation of results from faecal NIRS analyses and the options for management interventions are likely to be facilitated by local experience built up over time. Whatever the mechanism, resource monitoring by faecal profiling should provide an enormous boost to producer knowledge and understanding of the nutrition of grazing livestock, knowledge and understanding which can help to achieve sound management for economic viability and sustainability by means of informed decision making.

Limitations of faecal NIRS

Limitations fall into a number of categories which include limitations regarding: the range of attributes that can be predicted; the reliability and accuracy of predictions; and the benefits which the technology can provide to users of the technology.

Range of attributes

The 8 attributes for which calibration equations have been or are being developed at the Davies Laboratory do not represent the full range of attributes that can be predicted from faecal NIRS analysis. For example, calibration equations have been developed at Texas A&M University in the USA (J.W. Stuth, personal communication) and by a commercial company in Toowoomba for predicting faecal phosphorus (P) concentration. Prediction of dietary and faecal tannin levels is quite probable. In the USA, experiments have revealed that unique faecal chemistry resulting from gross differences in reproductive status can be detected by NIRS (Tolleson *et al.* 2000a) as can differences in parasite burden (Tolleson *et al.* 2000b). In fact, the number of attributes will almost certainly increase with time and with further advances in NIRS technology in general. Limitations to what attributes can be determined usefully by NIRS are partly due to the chemical and physical determinants of absorption and reflectance of radiation in the near infrared region. As a general rule, NIRS works best for determining the major organic compounds or components and less effectively for the quantitative analysis of minerals and minor organic components.

Reliability

There will always be some error associated with faecal NIRS analysis, but this is true with any form of NIRS analysis where predictive accuracy depends on the attribute being measured, the size and structure of the calibration set of samples, and the accuracy of the laboratory reference values used in the development of the calibration equation. However, the errors associated with determining dietary attributes from faecal NIRS will be somewhat larger than those that would be associated with direct NIRS analysis of the diet. Predictive accuracy is better for dietary N than for digestibility (see appendix) but this is equally true for forage analysis. Reduced accuracy in estimating dietary N and digestibility from faecal NIRS is due to both the difficulty in obtaining truly representative diet samples to match with the faeces of grazing cattle and the imperfect correlation between feed and faecal composition.

In north Australia, the size and structure of the calibration sets are currently the main constraints to reliable faecal NIRS predictions. In most NIRS applications, it is a simple procedure to build up large and diverse calibration sets. This simple procedure applies to faecal NIRS for the prediction of faecal N and faecal $\delta^{13}C$, where NIR spectra and laboratory reference values are both obtained on faeces. For the prediction of dietary attributes, however, matching diet and faecal samples are needed and this makes the process both difficult and expensive. Generating calibration samples and relevant reference values for predicting growth rate is easier and cheaper because diet samples are not needed. Nevertheless, building calibration sets in which reliable estimates of growth rate have to be matched with faecal spectra is more demanding than for most NIRS applications. At the present stage of development, considerable expansion in the number and diversity of samples in all calibration sets is needed to provide robust calibration equations for application across northern Australia.

The difficulties associated with developing adequate calibration sets where the laboratory reference values are not derived from the samples subjected to the NIRS analysis also occur in the validation process and the ongoing testing of the predictive accuracy of calibration equations. In most applications, NIRS predictions can be checked by carrying out standard laboratory analysis on the sample scanned in the NIR instrument. Apart from those predictions that relate to the faeces themselves, this is not possible for the non-faecal attributes being predicted (*i.e.* dietary and performance attributes).

Interpretation of results

Regardless of the accuracy of faecal NIRS predictions, results will be of little use unless they can be interpreted in a way that will be of benefit to managers. In many or most circumstances, the interest will be in the implications of the results for animal performance: the estimation of animal performance, the identification of limiting nutrients, and the determination of viable options for improving animal performance. Therefore, for most applications, faecal NIRS is not a stand-alone technology in terms of delivering benefits. Rather, it is a useful tool which, when used in conjunction with other technologies, can help producers make informed decisions about the nutritional management of their livestock. At present, there are inadequacies, not only in the faecal NIRS technology, but also in the associated technologies, *viz.* in nutritional models for determining animal performance from dietary and pasture attributes and technology for predicting responses to additional nutrients supplied by way of supplements. Both these associated technologies need improvement before the potential benefits of faecal NIRS can be fully realised. It is also true to say that the potential benefits of reliable nutritional models and models predicting responses to supplements cannot be fully realised without a technology that can provide reliable estimates of diet quality in free-grazing cattle.

Conclusions

Faecal NIRS is a developing technology with the scope for providing significant benefits in both commercial and research fields. The prediction of diet quality and animal responses has particular promise with regard to the nutritional management of grazing cattle, especially in the area of cost-effective supplementation. The technology requires further development before the commercial applications can be effectively exploited. The main requirement for further development is the expansion of calibration sets to improve the reliability of predictions across all regions.

Although faecal NIRS provides a raft of information that has previously been unattainable, the technology should not be regarded as anything more than a tool to facilitate good decision making. Better and more confident decisions may result simply from an improved understanding of the nutritional basis and complexities of rangeland production systems or from the provision of reliable, quantitative information relevant to the matter under consideration. The ability to make useful decisions assisted by faecal NIRS technology will improve as advisers and producers accumulate data and experience over time on diet quality, animal performance relative to diet quality and animal responses to supplement or other management interventions.

The simplicity of sampling and analysis, the short turn-around time, and low cost structure relative to standard laboratory chemical analyses are benefits favoring commercial adoption. Benefits to users of the technology are also likely to increase with time as a result of improved predictive accuracy, increased range of predicted attributes and a growing expertise based on accumulated knowledge and experience in the use of the technology.

Appendix:

Calibration equation statistics as at March 2000 for equations developed at the CSIRO Davies Laboratory, Townsville.

Attribute	SEC/SECV[1]	Range	R^2	(n)
Dietary CP(%)	0.99/1.02	1.94 to 25.38	0.94	645
IVDMD (%)	3.3/3.3	44 to 83	0.80	437
Faecal N (%)	0.08/0.09	0.70 to 2.99	0.95	360
Faecal $\delta^{13}C$	0.71/0.73	−13.04 to −28.59	0.95	756
Growth rate (g/d)	77/83	−200 to 1500	0.95	255

[1] SEC: Standard error of calibration.

SECV:Standard error of cross validation.

References.

CLEMENTS, R.J., JONES, R.M., VALDES, L.R. and BUNCH, G.A. (1996) Selection of *Chamaecrista rotundifolia* by cattle. *Tropical Grasslands*, **30**, 389–394.

COATES, D.B. (1999) Faecal spectroscopy (NIRS) for nutritional profiling of grazing cattle. *Proceedings of the VIth International Rangeland Congress, 19–23rd July 1999 at Townsville, Queensland, Australia.* Vol. 1, 466–467.

COATES, D.B., SCHACHENMANN, P. and JONES, R.J. (1987) Reliability of extrusa samples collected from steers fistulated at the oesophagus to estimate the diet of resident animals in grazing experiments. *Australian Journal of Experimental Agriculture*, **27**, 739–745.

DOVE, H. and MAYES, R.W. (1991) The use of plant wax alkanes as marker substances in studies of the nutrition of herbivores: a review. *Australian Journal of Agricultural Research*, **42**, 913–952.

JONES, R.J. (1981) The use of natural carbon isotope ratios in studies with grazing animals. In: Wheeler, J.L. and Mochrie, R.D. (eds) *Forage Evaluation: Concepts and Techniques.* pp. 277–286. (CSIRO Australia and the American Forage and Grassland Council: Melbourne).

JONES, R.J., COATES, D.B. and MCCASKILL, M.R. (1990) Pasture and climatic effects on cattle liveweight gain from stylo based pastures in the seasonally dry tropics. *Animal Production in Australia*, **18**, 260–263.

JONES, R.J. and LASCANO, C.E. (1992) Oesophageal fistulated cattle can give unreliable estimates of the proportion of legume in the diets of resident animals grazing tropical pastures. *Grass and Forage Science*, **47**, 128–132.

LEITE, E.R. and STUTH, J.W. (1994) Influence of duration of exposure to field conditions on viability of fecal samples for NIRS analysis. *Journal of Range Management*, **47**, 312–314.

LYONS, R.K. and STUTH, J.W. (1992) Fecal NIRS equations for predicting diet quality of free-ranging cattle. *Journal of Range Management*, **45**, 238–244.

MINSON, D.J. (1990) *Forage in Ruminant Nutrition.* (Academic Press: New York).

TOLLESON, D.R., WILSON, T.W., RANDEL, R.D., NEUENDORFF, D.A., LEWIS, A.W. and STUTH, J.W. (2000a) Discrimination between physiologically different groups of cattle via Near Infrared Reflectance Spectroscopy of feces. *Southern Section, American Society of Animal Science meetings, Lexington, KY, Jan 30–Feb 2, 2000.*

TOLLESON, D.R., TEEL, P.D., STUTH, J.W. and STREY, O.F. (2000b) Discrimination of parasite burden in livestock via Near Infrared Reflectance Spectroscopy of feces. *Southern Section, American Society of Animal Science meetings, Lexington, KY, Jan 30–Feb 2, 2000.*

WINKS, L., LAING, A.R., O'ROURKE, P.K. and WRIGHT, G.S. (1979) Factors affecting response to urea-molasses supplements by yearling cattle in tropical Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **19**, 522–529.